

44 MARKET ST – REFURBISHMENT OF A DUAL DUCT BUILDING

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ABSTRACT

44 Market St is a high profile, A-grade, 27-storey, 28,000m² office building constructed in the 1970s. In common with many other buildings of its era, it was equipped with a dual duct air-conditioning system, and its highest NABERS Rating at full occupancy was 2 stars without Green Power.

This paper describes the process of refurbishing the building including:

- Modifications to convert the air conditioning system to a variable volume dual duct system, re-using many of the components of the original system
- BMS replacement including control modifications throughout the system
- Separation of domestic hot water from the space heating boilers
- NABERS compliance modifications to the building.

The refurbishment works were completed in April 2012, and since then the monthly electricity consumption has halved and gas consumption reduced by 40% relative to weather corrected benchmarks. Using an average tariff of 24.8c/kWh for electricity and 1.75c/MJ for gas, that equates to a \$340,000 annual cost saving. A 4.5 Star NABERS rating was awarded to the building in January 2013.

BUILDING BACKGROUND

44 Market St is a 28,000m² Grade A office building located in Sydney CBD owned by DEXUS Property Group. The building consists of 25 office levels, a childcare centre on Level 1 and retail tenants on the Ground level. The building was constructed in the mid-1970s and refurbished in 1992 with National Mutual as the anchor tenant. In 2011-2012, the building underwent major works with hardware changes and further tuning of controls and BMS strategies. Upgrade works culminated in June 2012. The building is currently tenanted by a diverse mix of commercial tenants on its office levels.

The building was rated at 2 stars NABERS Energy base building (2.5 stars with Green Power) (OEH 2013) for its operation in FY2009/2010. The building has since improved in performance, achieving 4.5 stars (5 stars with Green Power) in the recent December 2012 NABERS Energy base building rating, due to the impact of works described in the paper (which were, however, not fully on line until mid-2012).

The building, prior to refurbishment, was as described below:

- Floor plate: The building floor plate is square.



Figure 1. 44 Market St Sydney

- HVAC:
 - The office floors and childcare centre were served by multiple dual-duct air handlers, while the ground floor (lobby and retail tenants) was mostly serviced by conventional single duct AHUs. The office

- floors on Levels 2 to 26 was serviced by two separate dual duct AHUs, with AHU-1 serving the low rise floors (Levels 2-13) and AHU-2 serving the high rise floors (Levels 14-26). The dual-duct air handlers have a cold deck total design supply volume of about 44,000L/s each and neutral deck total design supply volume of 26,000L/s each. Each AHU has a design 15,000L/s fresh air intake respectively. Both AHUs were configured with parallel 110kW supply fans serving neutral (termed as neutral deck on-site despite being supplied with heating and cooling coils) and cold decks. See Figure 2 for AHU-2 layout (AHU-1 is similar). The supply air fans were VSD controlled to maintain a static pressure set-point measured at the AHU. Both systems had East and West risers with two separate BMS controlled throttling dampers downstream of the fans. While the original intent of the throttling dampers was probably as balancing dampers for the East and West riser, in reality they were resulting in large pressure drops across the fans and throttling both risers. The low-rise system had an additional riser for the North facade.
- The dual-duct system on Level 1 (Childcare Centre) comprised of AHU-5A and AHU-5B, designed for 7,450L/s supply air. AHU-5A had its chilled water coil prior to the hot/cold deck split (see Figure 3), whereas AHU-5B had a standard dual-duct configuration with a chilled water coil in one duct, and hot water coil in the other. All mixing boxes had separately controlled neutral/cold dampers and were designed to be pressure independent (one flow sensor per mixing box).
 - Three AHUs serve the retail tenants (AHU-3, -6 and -B1) and one two-zone constant volume AHU served the ground foyer. AHU-3 was a multi-zone dual duct unit with a single supply fan and separate cooling and heating coils serving the retail bank and optometrist tenancies. AHU-6 (café) was a constant volume system equipped with cooling and heating coils. AHU-B1 (Australia Post on Basement 1 level), which was not under the control of the BMS, operated from the chilled water system and was fitted with electric heating.
 - Chillers: The building had four chillers, being two 1,730kW Trane centrifugal chillers (~COP 4.6, two 37kW CHW pumps at 48.2L/s each), one 1,100kW Trane screw chiller (~COP 4.4, 30kW CHW pump at 31.2L/s each) and one 400kW low load York reciprocating chiller (~COP4.4, one CHW

pump at 10.7L/s), all dating from the 1990's. These were configured on a primary-only loop servicing the office, childcare and retail areas of the building. All chillers were water-cooled via two open-cycle cooling towers (18.5kW fans) on a common header. Two separate open-cycle cooling towers (4kW fans) serviced the tenant condenser water loop.

- Boilers: The building had two Ygnette 1,465kW gas boilers (with non-modulating burners) on a primary-only pumping arrangement (two 11kW HHW pumps) to generate heating hot water and to service two 4,100L calorifiers for domestic hot water.
- Lighting: The lighting system comprised of four separate 'wiring schemes'. Most of the base building areas were wired for two circuits named 'Essential' and 'Non-Essential', and many spaces in the building core had two lighting switches. Power to those circuits were controlled by the BMS; however, the 'Essential' circuits were generally left running 24/7, resulting in an estimated 10% of the lighting load running continuously. In addition to the 240V circuits, the building contains a 110V DC central battery power emergency lighting system, and some areas of 240V emergency lighting as well. This lighting configuration added complexity to reconfigure existing wiring to regroup lights and minimise the amount of lighting that was left permanently running.

THE PROJECT: SCOPE OF WORKS

Initial Performance

The initial reviews of the building in 2010 and early 2011 by Exergy Australia identified a number of significant areas of opportunity for performance improvement, including:

- Controls: The site was controlled via an old (circa early 1990s) Johnson control system with electronic sensing and controls on the floors but with pneumatic actuation in the plant rooms.
- Boiler plant: The boilers operated continuously to service the calorifiers, as the thermal inertia of the large calorifiers led to unacceptably long start-up periods. The combination of long periods of low load operation using large non-modulating boilers led to very poor efficiency operation.
- Tenant condenser water system: The tenant condenser water pumps did not have VSDs installed and there was no flow regulation on the system. As a result the 15kW pumps operated at full speed 24/7.
- Air-side controls: Site staff reported significant issues with air flow inadequacy and pressure control throughout the building as a multi-floor air balance had not been conducted for more than 4 years.

- Air handling plant: The common supply plenum for the major air-handlers significantly limited the ability of the fans to turn down in response to load, and also meant that economy cycle operation was limited (due to the common plenum for neutral and cold decks). Furthermore, the riser dampers were not well commissioned, resulting in excessively pressures (>1000pa) at the fan outlet. AHU 5A was poorly configured, with a cooling coil followed by a hot deck and bypass deck (no cooling/heating coil) split, resulting in simultaneous heating and cooling.
- Terminal mixing boxes: While the mixing boxes were specified to have a pressure plate (i.e. a perforated plate across which pressure can be measured) to enable flow measurement and thus pressure independent flow, many boxes did not have these plates. This meant that the system ran as a pressure-dependent system, limiting fan turn down due to the need to maintain a fixed duct pressure; this also meant that the control of airflow in the mixing boxes was generally poor.
- NABERS boundaries: The retail air handlers AHU-3 (15kW) , AHU-6 (2.2kW) and AHU-B1 were fed entirely off base building boards for their fans, chilled water and hot water. As there was no separate retail chiller or sub-metering, the base building rating was also penalised by the chilled water servicing of the retail loads.
- Site management: Prior to 2010, the site had had the same building manager for many years. However on his retirement, hand-over had been insufficient leading to a steep learning curve for the incoming staff.
- Chiller plant: The four base building chillers were older models of average to poor efficiency (COP on average 4.5).

A \$4 million project was launched in January 2011 to address many of the opportunities described above. To minimise disruptions to occupants, the project first rolled out by conducting all hardware changes in the plant rooms and car parks, followed by floor by floor upgrades occurring after-hours and weekends. Once hardware changes were complete, controls for the floors were refined, followed by controls for air handlers, chillers and the central plant.

Upgrade Works – Hardware Modifications

In order to address the issues above, a significant suite of hardware upgrades was specified, including:

- Retail separation: A new Powerpax chiller was installed to service the retail air handlers. Meters were installed to exclude the electricity consumption of the retail chiller and retail air handlers, which improve the NABERS Office performance of the building (which penalises the rating due to the mixed office and retail servicing). Separation between commercial and retail servicing is also beneficial as the two types of tenancies have different trading hours and servicing requirements.
- Water and air balance: A complete proportional air-balance was conducted for Levels 1 to 26. A water balance was also conducted for the heating hot water and chilled water systems.
- AHU-1 and AHU-2 dual duct system: A dividing wall was installed between the cold and hot deck supply air fans, effectively changing the supply air configuration from two fans operating in parallel to two independently operating fans. The economy cycle was configured to only serve the cold deck.
- Pitot flow sensors were installed in all mixing boxes, providing measurement of total airflow. This modification enables pressure independent control of both the cold and neutral fans.
- AHU-5 and Level 1 servicing: The reheat in AHU-5A was demolished and removed. AHU-5A now supplies cold air to Level 1 mixing boxes, with hot air supplied from low-rise AHU-1B.
- BMS and elimination of pneumatic controls: A new fully integrated Schneider BMS, complete with remote web access, was installed on-site. A new web based tenant after-hours air conditioning request system was implemented. All pneumatic actuators were replaced with new 24Vac electric motors, allowing the pneumatic air station and compressor-receiver set to be removed. A CO monitoring and control system was installed for the car park ventilation system. On-floor zone temperature sensors were replaced and integrated with the BMS.

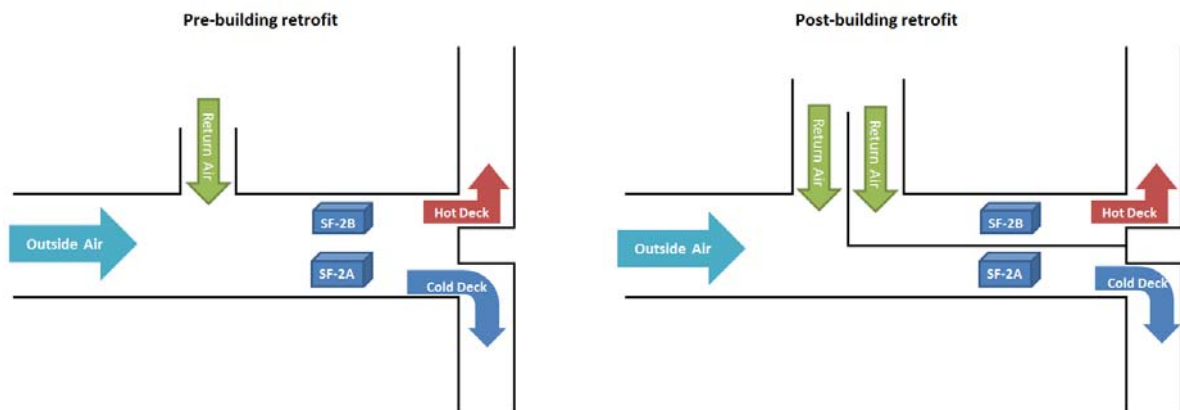


Figure 2: AHU-2 pre- and post-retrofit hardware configuration

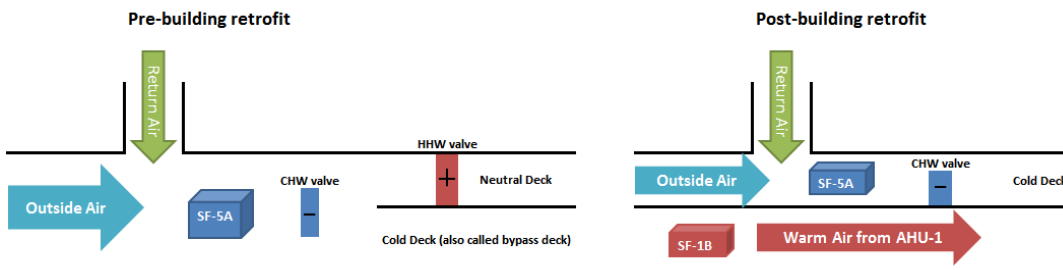


Figure 3: AHU-5A pre- and post-retrofit hardware configuration

- VSDs: VSDs were updated for cold deck supply fans AHU-1A and AHU-2A. The two tenant condenser water pumps were also fitted with new VSDs, facilitating pump turn down.
- Motorised valves: For each AHU, new motorised shut-off valves were installed on chilled and hot water valves, isolation valves and balancing valves.
- DHW system upgrade: The existing calorifiers were disconnected from the main heating hot water system, and are now heated by four new instantaneous hot water heaters. Two dedicated domestic hot water pumps were installed. The calorifiers are scheduled to be decommissioned in the near future, as their thermal inertia is continuing to be a hindrance to system efficiency.
- Boilers: The non-modulating boiler burners were replaced with fully modulating burners.

Upgrade Works – Controls Modifications

The key enhancements to building controls were as follows:

- Terminal mixing boxes (Figure 4 and Figure 5). Early reviews of box operation showed that while the mixing boxes were configured to

open the cold duct dampers proportionally to zone temperature, the parameters had been heavily modified over time. Under the refurbishment, the mixing box control was modified into a three stage system as follows:

- The relative position of neutral and cold duct dampers was set based on deviation from zone set-point. Under normal control, the cold damper operates from fully closed to open over the range $SP-0.5^{\circ}\text{C}$ to $SP+0.5^{\circ}\text{C}$, with the neutral duct operating to the reverse of this.
- Total flow is modulated by applying an overriding adjustment multiplier to the position of both dampers to obtain the required mixed flow. Flow increases from minimum to maximum from $SP+0.5^{\circ}\text{C}$ to $SP+1.5^{\circ}\text{C}$.
- When the neutral duct is in cooling mode and the zone temperature exceeds $SP+1.5^{\circ}\text{C}$, the neutral duct damper is opened from zero to 100% and the flow modulated from maximum to 1.2 times maximum. This combination provides variable volume control of total flow as well as

pressure independent variable volume control of the cold and neutral dampers.

- AHU fans. Supply air fan speed is now PI controlled to maintain the static pressure set point, which is reset based on the floor high-select of the average floor east group and average floor west group damper positions. This critical static pressure set point reset represents a large energy saving relative to the original fan speed control based on an excessively high static pressure set point (1,200Pa) measured at the AHU, with the throttling dampers located downstream of the supply air fans maintaining floor static pressure set points measured on two floors (L18 and L9). After-hours operation is based on a half floor basis achieved with the floor isolation dampers.

- AHU temperature control. This was originally programmed with the cold duct supply air temperature reset in 0.5°C increments from the 12°C minimum supply temperature, based on the control zone temperature taken from the high-select of four master floors. Supply air temperature control for the hot/neutral duct and economy cycle staging was unknown. As such, inefficient operation was observed in that both cold and hot ducts were being actively conditioned, simultaneously, for much of the time. In the upgrade works, supply air temperature control was changed to maintain at a set-point varying on separate reset schedules based on averaged low and high select zone temperatures for the neutral and cold decks. Economy dampers are activated as the first stage of cooling for the cold duct.

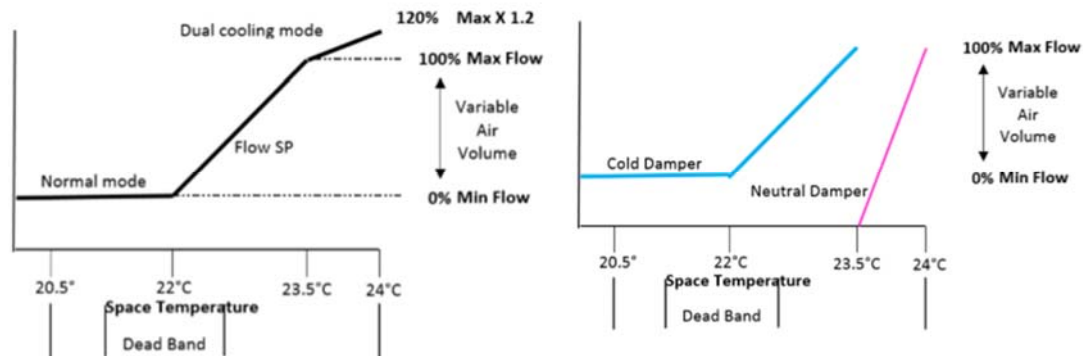


Figure 4: Terminal mixing boxes control - (Left) Air flow set point control in normal mode and dual-cooling mode. (Right) Mixing dampers operation in cooling mode.

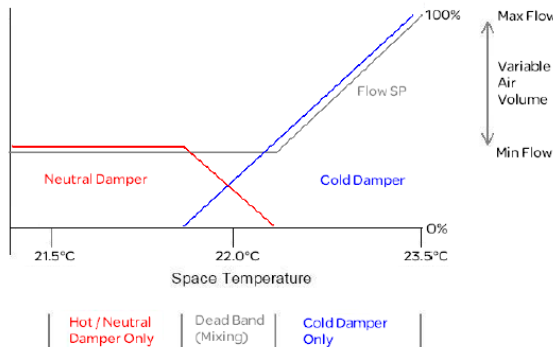


Figure 5: Terminal mixing boxes control – cold and neutral dampers operation in normal mode.

- Chiller controls were modified to stage chillers in accordance with chiller full load amps with a chiller outside air lock out in place. The chilled water bypass valve is controlled to maintain a minimum differential pressure across the operating chiller evaporator vessels corresponding to design flow
- Condenser water system. The largest energy saving within the condenser water system was the installation of VSDs on tenant condenser water pumps, given that the tenant condenser water system has to run 24/7. This allows the

pumps that used to operate at constant speed to be turned down to maintain a low differential pressure set point (set to 80kPa).

- Cooling towers. The revised control modulates the cooling tower fan speed using PID control to achieve the condenser water set point, which is reset by the ambient wet bulb temperature plus 5°C, subject to minimum and maximum limits of 24°C and 29°C. The existing chillers do not permit condenser water temperature to be lowered below 24°C.
- Hot water system. A boiler lock out has been instituted to prevent heating hot water system operation above an ambient temperature of 17°C.
- Lighting system. Base building lighting is now time-controlled via the BMS. After-hours operation is activated via PIR motion sensors.

OUTCOMES

Results from the retrofit have been positive. The building was awarded 5 stars NABERS (17.9% Green Power) in January 2013, having essentially halved its energy consumption on a month to month basis compared to the benchmark rating of 2.5 stars NABERS (12.4% Green Power) in 2010. Analysis of the base building electricity and gas

consumption trend is illustrated graphically in Figure 6 and Figure 8. Using an average tariff of 24.8c/kWh for electricity and 1.75c/MJ for gas, that equates to a \$340,000 annual cost saving, equating to a 12 year payback, which is good given that the capital costs included end-of-life replacement for the controls.

The estimated progress of the building's NABERS energy star (with 0% Green Power) rating relative to annual consumption is shown in Figure 10. The figures show positive results from the upgrade works completed in 2012. Applying the same percentage savings using the baseline electricity consumption trend projects that the retro-furnished dual-duct building will perform at 5 stars NABERS (without Green Power) by the anniversary of the conclusion of refurbishment works.

From a tenant comfort perspective, the project has been successful, with the feedback from tenants indicating that temperature control is considerably improved, although some initial adjustment of both controls and tenant understanding of the air-conditioning operation was required to achieve this outcome.

Note that the benchmark in Figure 8 is indexed back to 2009 as 2010-2011 had significant levels of vacancies. The reason for the high gas consumption between April and September 2011 is not certain, but could be due to lower levels of occupancy or to differences in weather from 2011 (Figure 7 and Figure 9) relative to that characterised in the 2009 benchmark.

LESSONS LEARNT

It is worthwhile to consider the lessons learnt, and apply it as a pointer to other projects.

1. **Commitment.** This project was largely driven by the building owner's (DEXUS Property Group) commitment to develop an office portfolio average of 4.5 stars NABERS by 2012. The success of 44 Market shows the importance of having the top management involved and vested in building improvement.
2. **The importance of control.** The success of the building refurbishment is driven largely by better control of existing systems rather than the wholesale replacement of plant. This is particularly important given that the underlying building design, being dual duct, is of one of the least efficient types available, and yet the achieved performance is best practice. This supports the contention that transformation of the property industry can be achieved without wholesale plant or building replacement, which is in itself an important environmental and financial outcome

3. **Latent defects.** The degree of latent deficiency and defect in the building before the refurbishment was greater than expected. This was due to a number of factors including deficiencies in the original design (such as the absence of flow monitoring plates in many mixing boxes), implementation details (balancing valves had to be installed throughout much of the chilled water and hot water systems to enable proper commissioning) and general decay through wear and tear. A thorough condition assessment earlier in the project would have reduced delays and costs associated with progressive uncovering of such issues.
4. **Viability of variable volume dual duct.** The project has illustrated that conversion of a traditionally designed dual duct system to a variable volume dual duct system is not only viable but also highly effective at achieving improved energy and temperature control outcomes.
5. **Potential for further savings.** The chiller plant is of at best average efficiency and could be improved considerably in terms of efficiency. However, this expensive investment has not been necessary to achieve a high level of performance. Assuming that the currently predicted high 5 star performance is achieved, upgrade of chiller plant may enable the achievement of 5.5 stars. This is a significant achievement for a building of this age and technology.

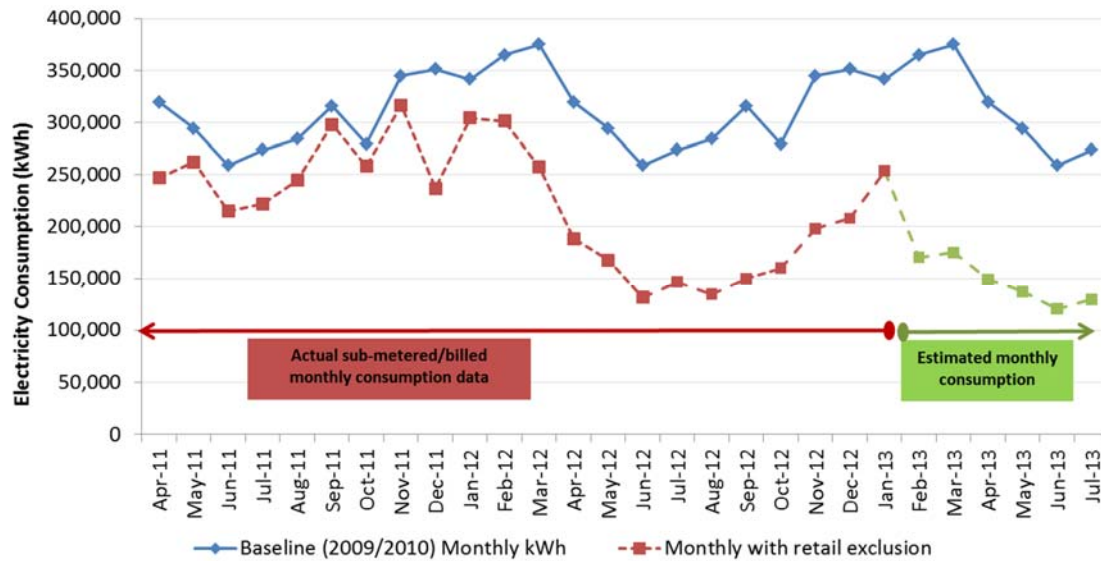


Figure 6: Base building electricity consumption trend

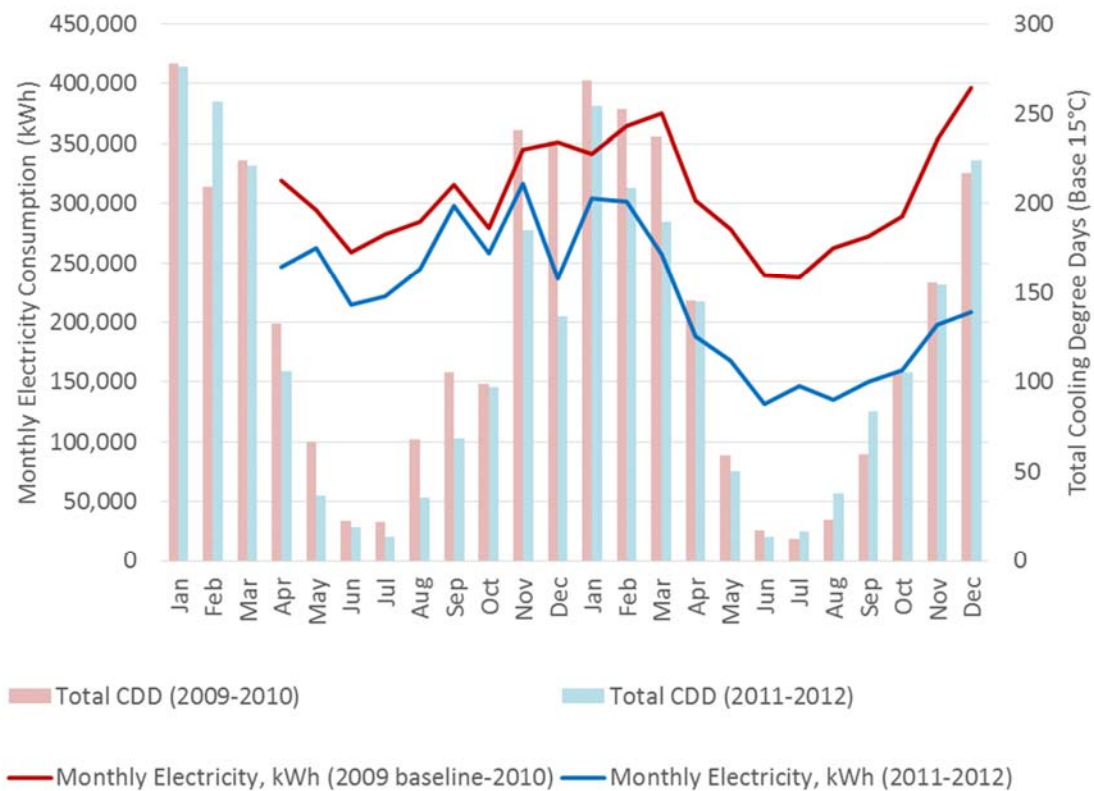


Figure 7: Base building monthly electricity consumption trend against base 15°C total cooling degree days (CDD)

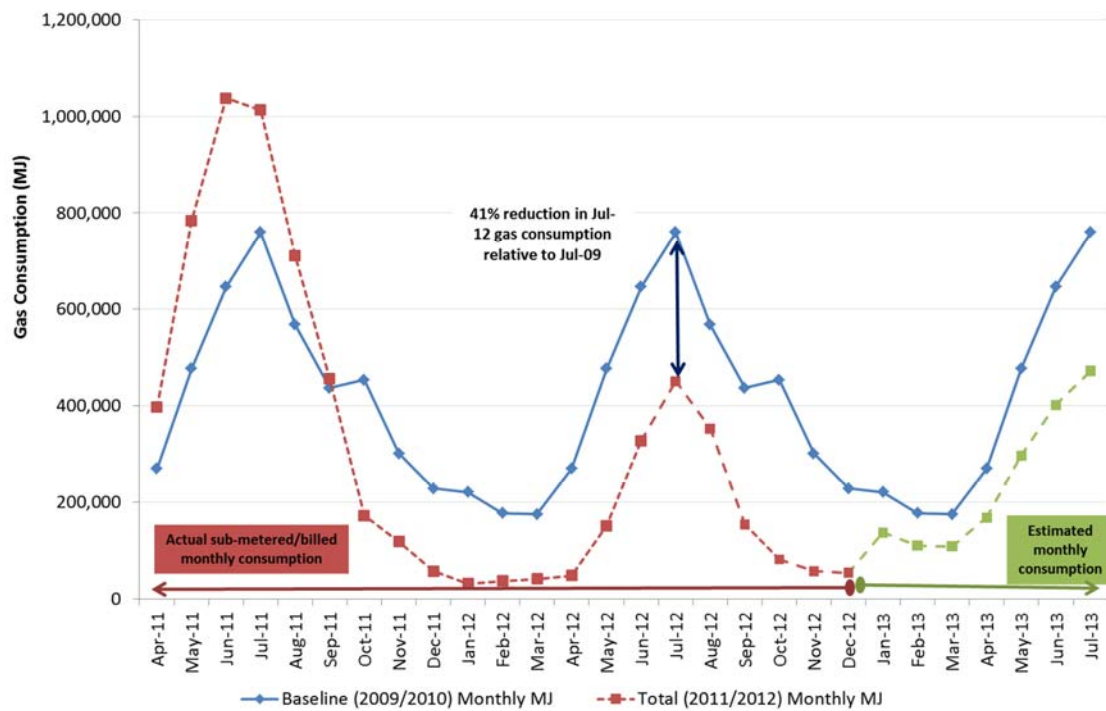


Figure 8: Base building gas consumption trend

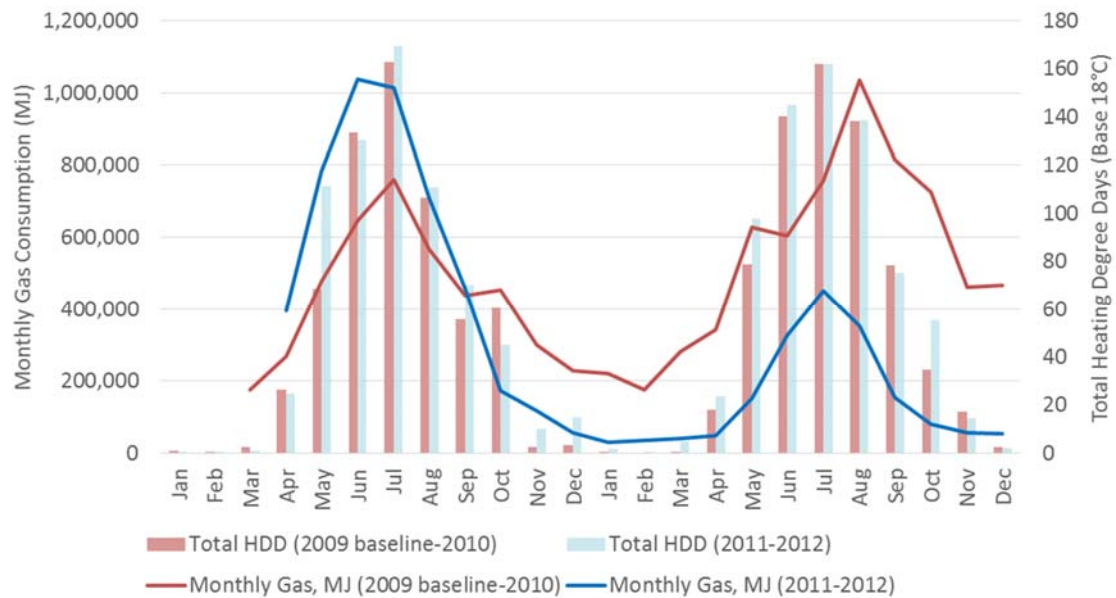


Figure 9: Base building monthly gas consumption trend against base 18°C total heating degree days (HDD)

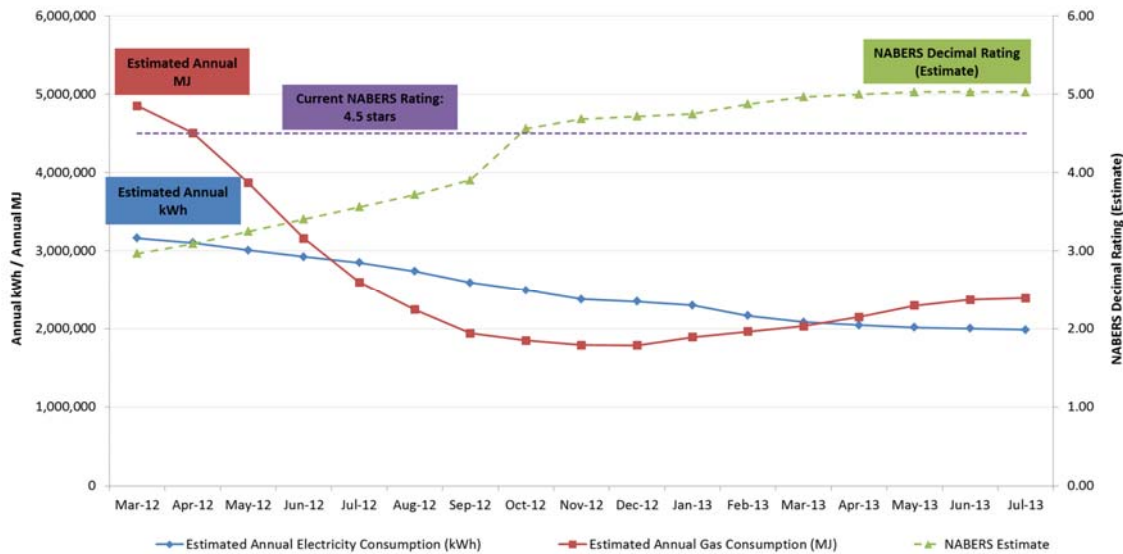


Figure 10: Monthly performance relative to star bands and progress towards 5 stars

CONCLUSION

Dual-duct systems are generally considered to be an energy intensive HVAC solution, and when combined with an older building the efficiency performance potential could be reasonably expected to be poor.

In this project, however, the refurbishment of dual duct system has resulted in an energy saving of the order of 50% with a project NABERS performance of 4.5 stars, with potential for further improvement. This demonstrates the importance of intelligent and well targeted refurbishment as opposed to system or building replacement as a means of upgrading building performance amongst the existing building stock.

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